Neural coding of speech and language : fMRI and EEG studies

CHAPTER 7

Knowledge Valorization

This thesis aims to understand fundamental neural mechanisms underlying the human ability to communicate via language. Such ability empowers people from all countries, cultures and religions to structure and communicate their thoughts. Effective verbal communication requires a neural system able to interact with and integrate sensory information from multiple modalities, such as audition and vision, to translate perceptual input to meaning-based memory representations during speech perception and to transform the intended message to motor actions for speech production. This thesis builds upon an intrinsic curiosity for this fascinating and highly efficient cognitive capacity. Understanding basic neural mechanisms of speech perception in the healthy adult brain will provide an important benchmark for studying normal and problematic language development throughout the lifespan. In the long run, the knowledge and method development generated by this thesis will help addressing unresolved language and speech disorders that impair millions worldwide. Persons with communication disorders, such as dyslexia, stuttering, apraxia of speech or specific language impairment (SLI) suffer from an impoverished quality of life. Additional fundamental knowledge on the neural systems supporting speech and language may in the future lead to a significant improvement of treatments and prevention strategies that are at present only partly effective. In particular, understanding the complex mechanisms underlying speech and language may empower clinicians with individually tailored solutions that may reveal imperative to achieve successful results in such diverse and variable clinical conditions.

Overall, our understanding of neural information hidden in small electric signals and chemical changes, revolving around billions of microscopic neurons and neural connections in the human working brain remains critically limited. Necessary progress in unravelling the neural mechanisms of speech and language in the healthy brain demands a fusion of well-designed cognitive/psycholinguistic paradigms and state-of-the-art non-invasive brain imaging techniques. This thesis aims to advance on both these directions: first, by designing more optimal ways to investigate at fine-grained level of detail the processing of individual spoken sounds; and second, by applying novel analysis

schemes that permit unraveling information content from brain responses to spoken sounds across different stimulus dimensions and cortical regions.

Translation towards speech and language development and disorders

Recent developments in brain imaging and brain stimulation technologies have inspired researchers to adopt novel approaches towards the treatment and identification of biomarkers for speech and language disorders. Technologies such as EEG, (f)MRI, TMS (transcranical magnetic stimulation) and TCS (transcranical current stimulation) in combination with neurofeedback solutions show potential to target normal and abnormal speech and language development with unprecedented detail. As these technologies improve at a fast rate, it is crucial to find direct and mechanistic evidence for their potential translation to clinical settings. Naturally, no animal testing is possible in speech and language research and thus, clinical approaches must have strong scientific foundations. Our work aimed to set an additional building brick on such foundations. The experimental paradigms and analysis approaches could be used to study the refinement of perceptual, articulatory and meaning based neural representations during normal and deficient language development. For example, they can help in clarifying why individuals show such large differences in the ability to learn a second/new language, and in understanding underlying deficits in children that struggle in learning to read due to poor decoding skills (developmental dyslexia) and/or more general comprehension deficits.

Further uncertainty exists in the relationship between speech perception and production. Speaking and listening seem to be highly interactive components of the same speech processing system. However, brain imaging studies find variable activations when subjects perceive or produce speech. Analysis schemes based on pattern generalization approaches used throughout this thesis promises to investigate commonalities between such systems that may

reveal crucial to understand their interdependence in everyday life, normal and abnormal development. For example, the foundations of speech production impairments may include a deficient activation of predictive auditory templates during online production and/or a deficient parsing of auditory speech sounds onto articulatory representations at some point of the person's development. Moreover, dyslexia may include a similar erroneous mapping between written, auditory and articulatory representations during a critical developmental stage.

Methodological innovation

The projects in this thesis adopted a combination of carefully controlled experimental stimuli and designs with multivariate fMRI/EEG decoding techniques. This provides an innovative approach to investigate information content from patterns of brain responses to speech, language and reading. Generalization approaches are valuable to investigate higher-order representations across several fields of neuroscience, such as object recognition, language, memory as well as feelings and emotions.

We further investigated a new method that aimed to assess communication between brain regions during specific cognitive states. Complementary to overall activity of different brain regions, inter-regional communication during high-order cognition, such as speech perception is fundamental to describe the operational networks of speech and language processing. Similarly, other high-order cognitive capacities rely on distributed brain networks. Our method seeks to unravel the transfer of information availability across the brain, thus promises to better characterize such cognitive capacities.

Finally, as our understanding of brain patterns across fMRI and EEG responses increase, it becomes attractive to develop translation mechanisms of fMRI patterns to more accessible and portable imaging techniques, as provided by EEG or fNIRS (functional near-infrared spectrocospy), which promise to play a central role in therapeutic solutions for speech and language.